Table 5-12. List of Possibly Anomalous Data

1*	#3	229151	229175	24	-15.8	104104.5	82692
1*	#3	229411	231305	1894	2.2	13105.9	92782
1*	#4	229153	229175	22	-15.8	104104	82693
1*	#4	229413	229523	110	2.2	13105.9	5845
25*	#19	421861	423495	1634	4.2	11806	26431

Table 5-13 contains the worst case performance when the data from Table 5-12 are excluded for aviation and non-aviation receivers. This represents the greatest effective distance at which these receivers lost the ability to navigate.

Table 5-13. Worst Case Performance

Type	Receiver	Description	Effective Range
Aviation	#22 & #3	Single Channel Ramp – TE 2	1041 m
Aviation	#1	Dual Channel Ramp – TE 17	1826 m
Non-Aviation	#21	Single Channel Ramp – TE 1	5147 m
Non-Aviation	#21	Dual Channel Ramp – TE 18	7449 m

It is expected that further analysis will be conducted to examine the more detailed behavior of receivers in the LSQ signal environment.

Live Sky Testing

(The GPS LightSquared Live Sky Test Plan Draft -- 7 April 2011, is an FOUO document and not releasable)

FAA

Summary

FAA participated in Live Sky Tests at Holloman AFB on 14-17 April 2011. There were two components to FAA tests; 1) flight tests with various aviation receivers, and, 2) ground tests with WAAS reference and CMC aviation receivers. This report focuses on quick look observations from ground test receiver analysis. Summary observations:

- Receiver #5 tracked through *all* LSQ test signals generated with no loss of signal tracking for satellites above 5 degrees elevation. While signal tracking was not impacted, there were anomalies observed with LSQ signal generation that resulted in questions on the validity of this testing. For example, LSQ 5 MHz High (designated 5H) signal generation was the only signal that resulted in significant C/No degradation (approximately 9 dB) but this degradation was not observed consistently since other 5H test periods resulted in negligible degradation. The only other LSQ test configuration that resulted in C/No degradation was the 5 MHz Low/5 MHz High test (5L/5H). The C/No degradation was 1 dB for this LSQ test configuration.

- Receiver #1 tracked through *most* LSQ test signals generated but lost lock on a significant number of satellites with the 5L/5H Phase 1 configuration. C/No data have yet to be processed for this receiver so observations quantifying potential degradations cannot be provided. It is also important to note that results from the 10 MHz Low/10 MHz High Phase 2 dual channel configuration for this receiver are *not* considered representative. The antenna used during this period of testing is not suitable for use in aviation applications.

The physical distance from FAA antennas to the LSQ transmit tower for these tests was approximately 451 meters but the effective distance was much greater. This effective distance takes into a 3 dB reduction based on Balloon pad calibration data and the maximum EIRP reported for LSQ signals of 57.4 dBm which is almost 6 dB less than the stated level by LSQ. Balloon pad calibration indicated significant variation across the pad which along with fundamental LSQ signal generation mentioned above is of concern for validity of these tests. The effective distance for FAA equipment considering this lower radiated power and pad calibration correction was therefore approximately 1.2 km.

Discussion

FAA testing conducted on the Balloon Pad at Holloman AFB included Receiver #5 and Receiver #1. (Other receivers were tested but those units are not pertinent to the FAA aviation focus). Receiver #5 was connected to a WAAS-125 antenna for both days while Receiver #1 was connected to a aviation antenna for 15 April and a survey antenna for 16 April. The survey antenna filtering and gain are not appropriate for use with an aviation receiver and therefore Receiver #1 results from the 16th are not considered valid or representative. In addition to these GPS receivers, instrumentation for time domain sampling (a Zeta 'Snapshot System') of the RF environment was included in the test configuration and connected to the WAAS-125 antenna.

The LSQ transmit tower was located approximately 451 meters from the FAA data collection location on the Balloon pad. Free space loss for this distance for a signal at 1552.7 MHz is 89.3 dB. However, calibration of the signal strength at the balloon pad conducted at the start of testing on 15 April indicated signal loss at the FAA data location was approximately 3dB greater than free space loss would predict. This equates to an effective distance for LSQ testing of approximately 631 meters. In addition, the LSQ EIRP reported for these tests was approximately 5.7 dB lower than stated by LSQ. Taking this lower power into consideration indicates that the effective distance was approximately 1.2 km or greater. LSQ signals generated during these tests were 5 MHz High, 5 MHz Low, 5 MHz High and Low simultaneously, 10 MHz High, 10 MHz Low, and 10 MHz High and Low simultaneously. 5 MHz was centered at 1552.7, 5 MHz low at 1528.8 MHz, 10 MHz High at 1550.2, and 10 MHz low at 1531.0 MHz.

The signal level present at the WAAS antenna LNA input was an important consideration given the LNAs high gain of approximately 48 dB and 1 dB compression point of 10 dBm. Table 5-14 uses estimates for the reported 5H signal LSQ EIRP for this configuration, effective signal loss and WAAS antenna performance to provide a signal level at the LNA input of approximately -45 dBm. An estimate was also generated using spectral data collected during two 5H tests. These results are provided in Table 5-15 and suggest a range of values from -42 to -48 dBm. This range is related to variation observed with the 5H signal during testing and is discussed in greater detail in a later section of this report.

Table 5-14. LSQ Power at WAAS Antenna LNA Input from Reported LSQ EIRP

Description of Link Budget Parameters	Estimates
GPSD Reported EIRP of LSQ Signal (5H 20W)	+57.3 dBm
Free Space Loss for Distance between WAAS Antenna and Tower (~451m)	-89.3 dB
Adjustment based on Pad Calibration (26.3 – (-66)) – Free Space Loss	3.0 dB
Effective Loss--Free Space Loss plus Adjustment (effective distance ~631m)	-92.3 dB
LSQ Signal Power at FAA Van	-35.0 dBm
WAAS Antenna Pattern Gain at ~5 Degrees -7 dBic or -10 dBil	-10 dB
LSQ Power at Input to WAAS Antenna LNA	-45.0 dBm

Table 5-15. LSQ Power at WAAS Antenna LNA Input from Snapshot Measurements

Description of Link Budget Parameters	Estimates
Snapshot Power Level (5H Distorted/5H Not Distorted)	+12 dBm/+6 dBm
Attenuation Set in SnapApp (no Gain)	-17 dB
Gain of Snapshot External Amplifier	+33 dB
Loss from Cables/Splitter from WAAS Antenna Output	-10 dB
WAAS antenna amplifier Gain	+48 dB
LSQ Power at Input to WAAS Antenna LNA	-42 dBm/-48 dBm

Tower Location: 32.8658N, -106.1265E, 1245m (altitude assumed 30m higher than WAAS antenna)
WAAS Antenna Location: 32.86935N, -106.1288.2E, 1215m
Distance between tower and WAAS antenna = 450.7m

Analysis of Receiver #5 data focused primarily on L1 C/A signal tracking and C/No observations. For Receiver #1, only L1 C/A signal tracking was available for this quick look analysis. Figure 5-29 shows a representation of Receiver #5 L1 C/No computed for all GPS satellites tracked. This C/No data is computed by correcting each satellite for nominal antenna gain and satellite power and then averaging all these corrected values for each time step. (If the receiver were operating as expected with no RFI present, this metric would indicate zero dB).

Figure 5-29 shows this C/No metric for the entire April 15th test period and highlights each specific test conducted. The large C/No degradation is associated with the 5H Ramp test and there is a question concerning the validity of this signal since the 5H test configuration did show consistent performance throughout the testing (more detail in a later section). The only other period where noticeable C/No degradation was observed occurred with the 5L/5H Ramp and Full Power (20W) tests conducted at the end of this test period. The C/No degradation was approximately 1 dB for this LSQ configuration. Figure 5-30 shows the number of GPS L1 signals tracked by both Receivers #1 and #5. Receiver #5 only shows GPS L1 signals while Receiver #1 shows GPS plus SBAS. For comparison purposes, the number of L1 signals tracked for Receiver #5 was increased by two to represent SBAS tracking. This Figure shows that Receiver #5 tracking was not impacted by any of the LSQ signals and Receiver #1 tracking was impacted only when 5L/5H was generated. The Receiver #1 tracking degradation for this LSQ configuration is rather dramatic with only four L1 signals being tracked.

Figure 5-31 and Figure 5-32 show the same observations for 16 April testing. As noted previously, Receiver #1 used a non-aviation antenna for this test period so its results are not shown. With the brief exception of a 5H test transmission that was aborted, Receiver #5 C/No degradation for this entire test period is considered negligible. The 5L/5H LSQ configuration impact appeared to be only 0.5 dB for this test sequence. Lastly, L1 signal tracking was not impacted for Receiver #5 throughout the 16 April test period.

Finally, Table 5-16 provides a summary of Receiver #5 and Receiver #1 observations from 15 and 16 April 2011 LSQ testing.

Table 5-16. Tracking and C/No Observations for Various LSQ Signals Tested

Signal Tested	Receiver #1	Receiver #5
5H	Lost tracking on one SV	Negligible to 9 dB C/No Degradation; *LSQ Signal Validity Questioned*
5L	No Impact	No Impact
5L/5H	Loss of Tracking on all but Four Satellites	1 dB C/No Degradation
10H	No Impact	No Impact
10L	No Impact	No Impact
10L/10H	Receiver #1 Observations Not Considered Valid	No Impact

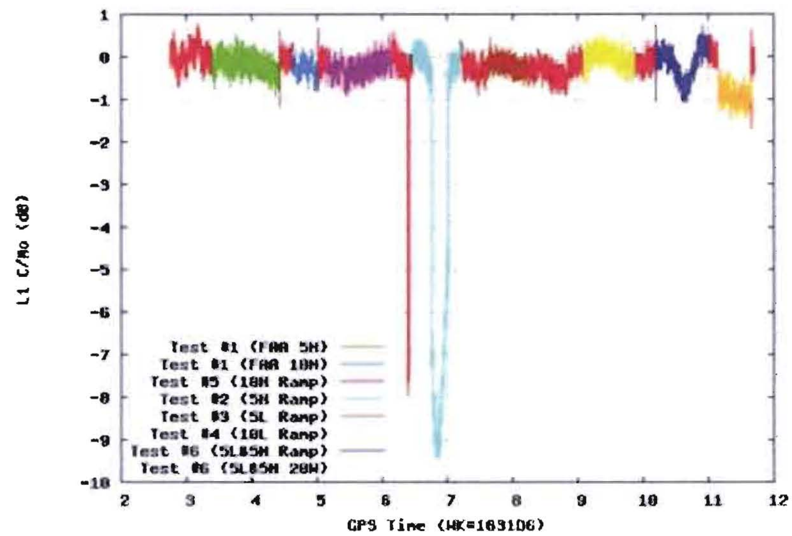

Figure 5-29. Receiver #5 L1 C/No Corrected for Nominal Antenna Gain and GPS Signal Strength for 15 April 2011. Large C/No Degradation Associated with 5H Signal Generation Anomaly.

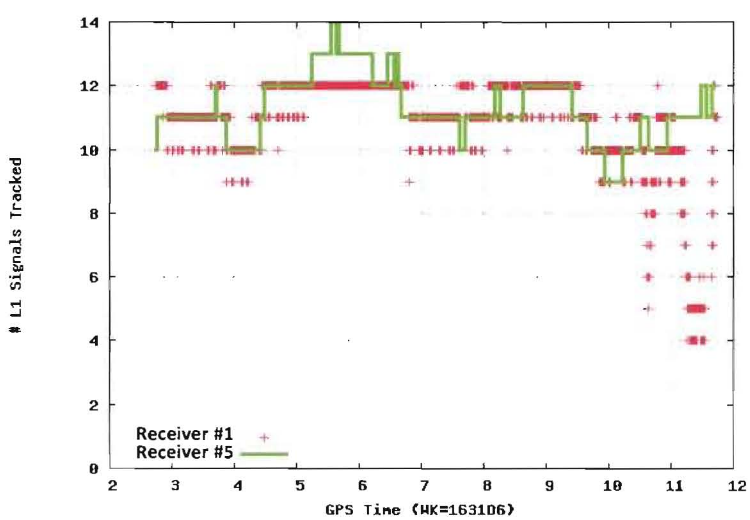

Figure 5-30. Number of Receiver #1 and Receiver #5 L1 Signals Tracked during 15 April 2011 LSQ Testing

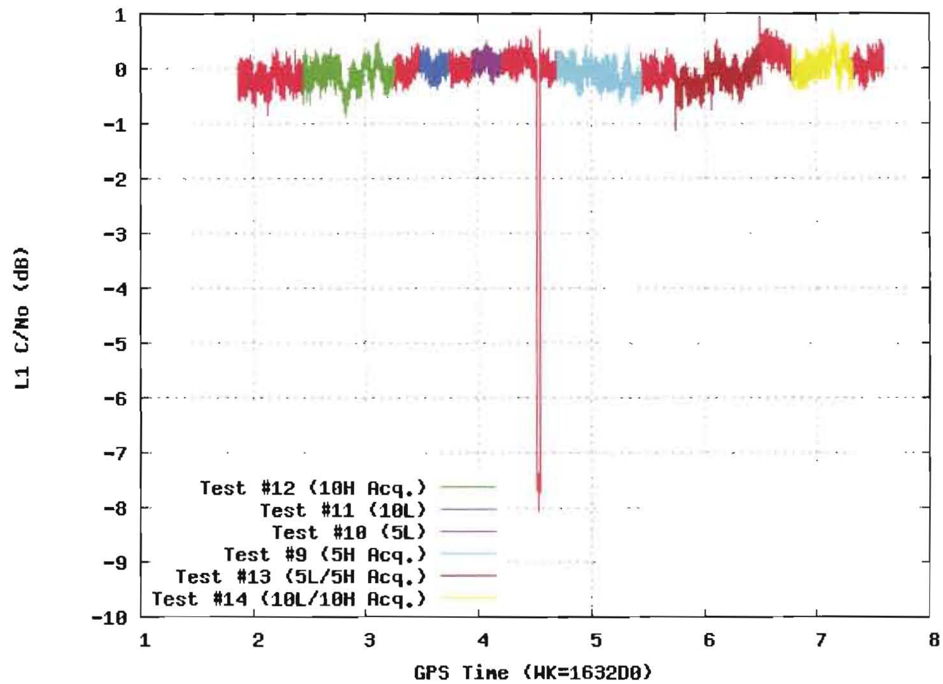

Figure 5-31. Receiver #5 L1 C/No Corrected for Nominal Antenna Gain and GPS Signal Strength for 16 April 2011. Large C/No Degradation Associated with 5H Signal Generation Anomaly.

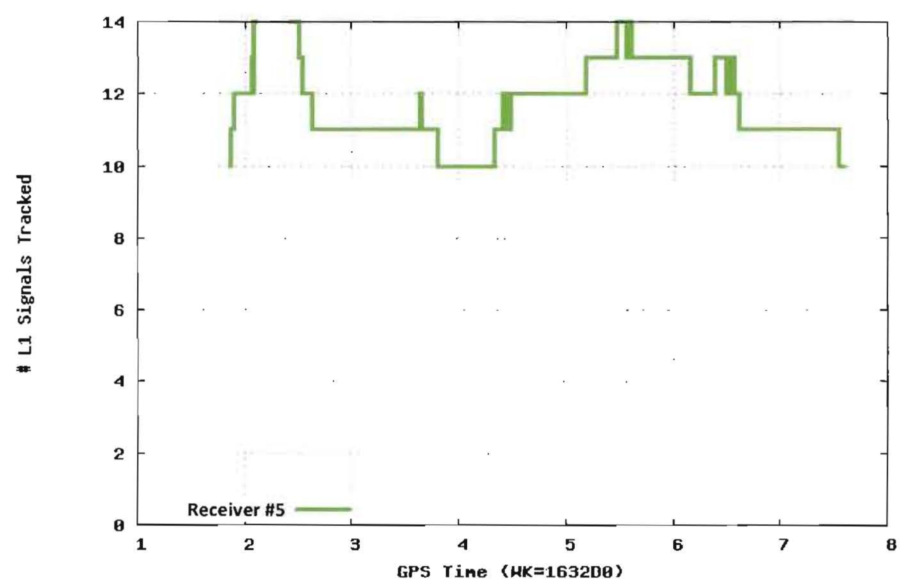

Figure 5-32. Number of Receiver #5 L1 Signals Tracked for 16 April 2011 LSQ Testing

LSQ Signal Generation Anomaly

Quick look analysis was performed using FAA data collected from the balloon pad for 15 April and 16 April tests. GPS receiver data utilized for this quick analysis was obtained from Receivers #5, 23, 25 and 19. Receiver #5 was connected to a WAAS-125 antenna (2225NW) for both test days while Receivers #23, 25, and 19 were connected to a aviation antenna on Day 1 and a survey antenna on Day 2. In addition to GPS receiver observations, the RF environment was sampled during critical test points with instrumentation capable of time domain sampling. This instrumentation was connected to a WAAS-125 antenna for both test days.

Figure 5-33 shows L1 AGC response from Receiver #5 for 15 April testing with various LSQ test configurations highlighted in different colors. Figure 5-34 shows the number of satellites tracked for Receivers #23, 25 and 19 for the same time period as Figure 5-33 (Receiver #5 did not experience any loss of tracking so its data is not shown). LSQ test configurations are highlighted at the bottom of Figure 5-34. Figure 5-35 and Figure 5-36 show the same information for 16 April testing. Figure 5-37 and Figure 5-38 show spectral plots comparing specific LSQ test configurations.

One significant concern from these initial observations is the validity of the LSQ signals generated during these tests. This concern was highlighted during 16 April testing when the 1st attempt at 5H step testing (Test #9) was halted because it was reported the waveform was distorted. This "distorted" signal resulted in the Receiver #5 AGC algorithm becoming fixed (AGC jump to ~6000 count level—possibly saturated) which is indicative of significant power present at the receiver's input. The LSQ signal generator was reportedly reset after this distortion was observed and the power indicated by the Receiver #5 AGC response in subsequent conduct of Test #9 was relatively benign (this performance can be seen in Figure 5-31). Receiver #5 AGC response indicating the presence of lower power was further confirmed with spectral plots shown in Figure 5-37 and Figure 5-38. Figure 5-37 compares spectrums of LSQ 5H from Test #9 (20W Step) of the "distorted" waveform and after LSQ equipment was reset (again, 20W Step). The signal power after reset is much lower, consistent with Receiver #5 AGC observations. Figure 5-38 provides a further comparison showing the LSQ 5H signal from Test #9 (20W Step) with the LSQ 5H signal from Test #13 (20W Step). Test #13 used simultaneous 5L/5H signals and the power observed for the High signal is again greater than observed with Test #9 after LSQ equipment was reset. This is also confirmed in Figure 5-35 with Receiver #5 AGC response and generally consistent with satellites tracked from Receivers #23, 25 and 19.

These observations and observations from 15 April call into question the validity of the 5 MHz High LSQ signal generated during these tests. The validity of this signal is particularly important to FAA since it appears the LSQ signal generated during the FAATC flyovers on 15 April may *not* have been conducted with a representative signal.

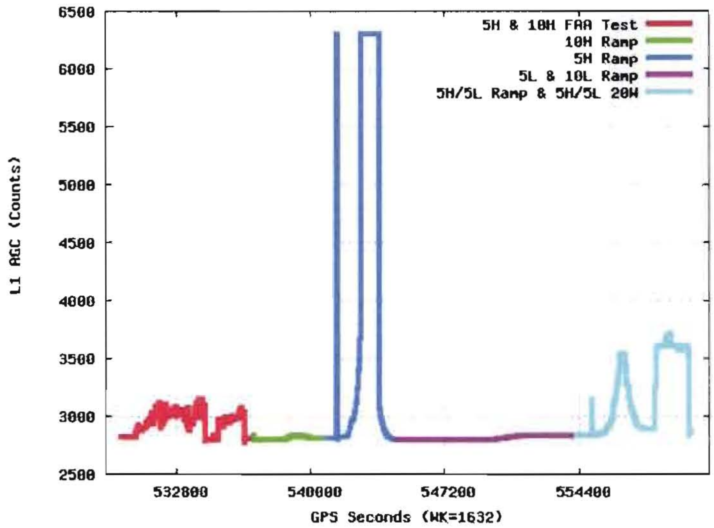

Figure 5-33. AGC Response for Receiver #5 from Day 1 Testing

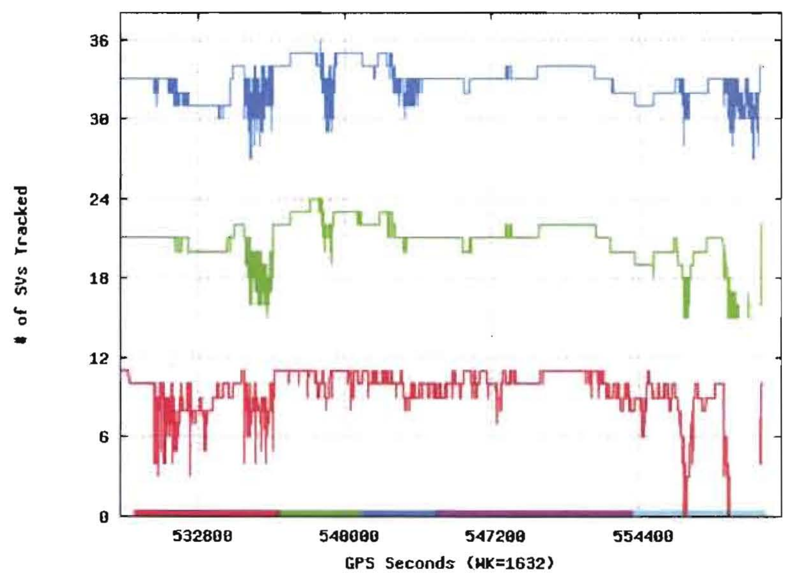

Figure 5-34. Number of Satellites Tracked for Receivers #23, 25 and 19 from Day 1 Testing

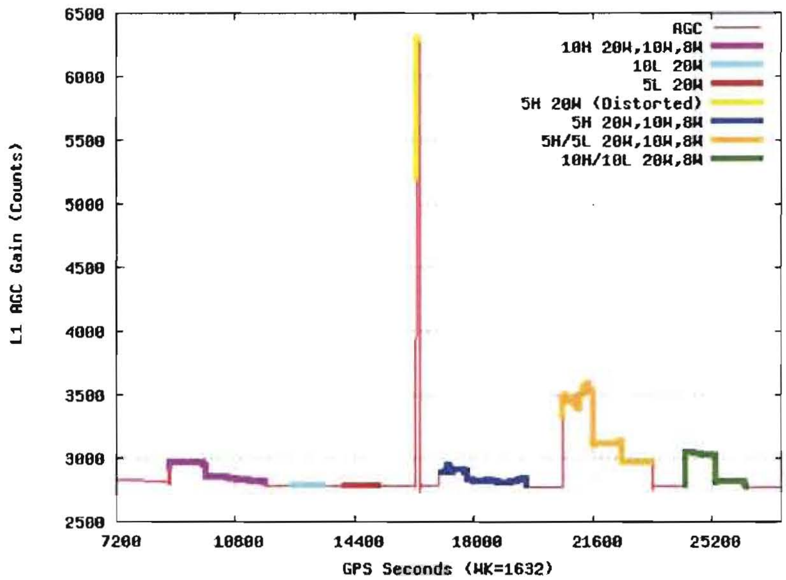

Figure 5-35. AGC Response for Receiver #5 from Day 2 Testing

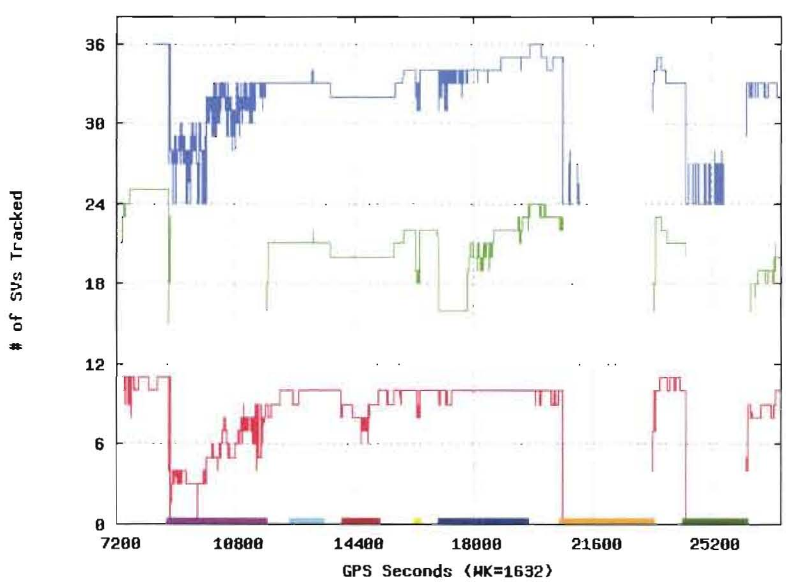

Figure 5-36. Number of Satellites Tracked for Receivers #23, 25 and 19 from Day 2 Testing

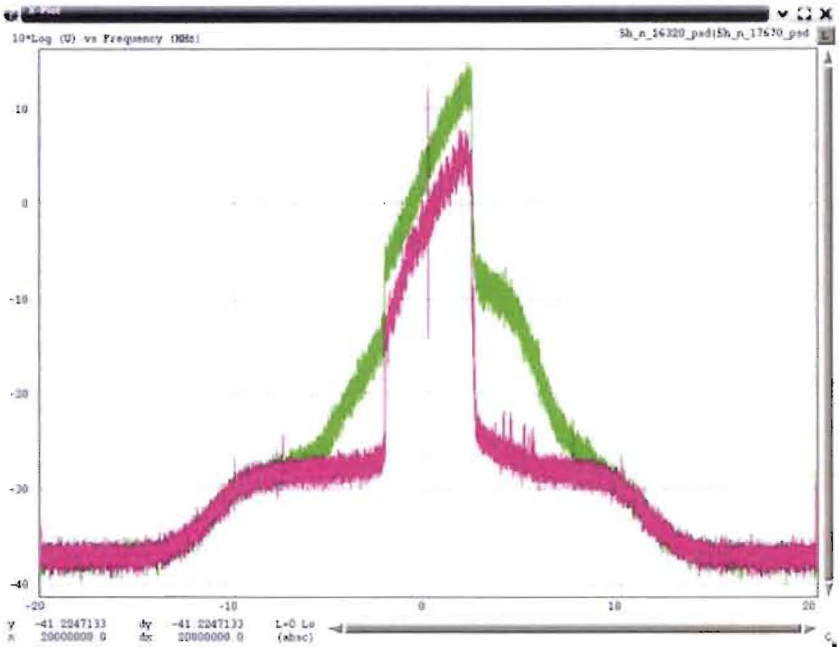

Figure 5-37. Comparison of 5 High Step Test from Day 2 (Test #9) of "Distorted" Waveform (Green) and Waveform Generated after Reset of LSQ Equipment (Magenta). Distorted Waveform is approximately 6 dB Higher in Power when both were reported at 20W.

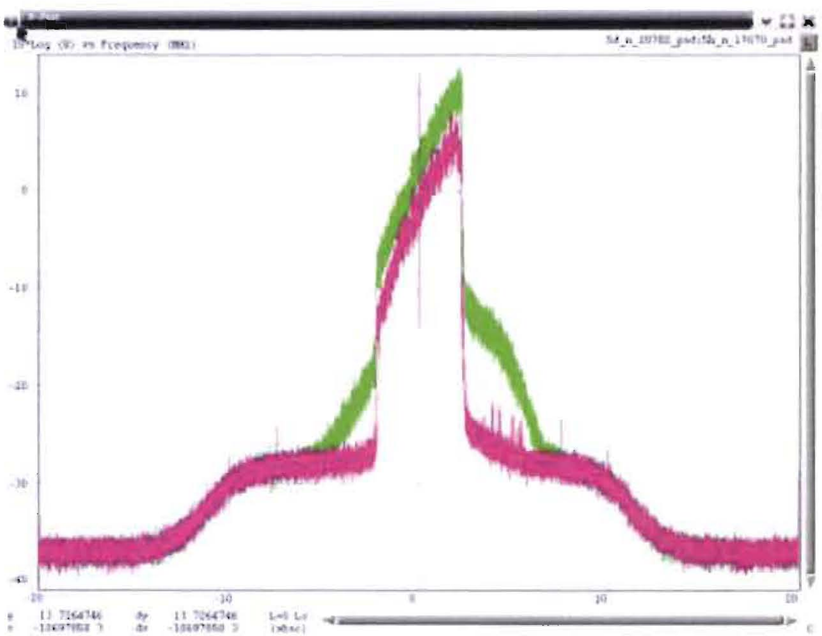

Figure 5-38. Comparison of 5 MHz Step Test from Day 2 (Test 9) after Reset of LSQ Equipment (Magenta) with Simultaneous 5MHz High/Low (Green) Waveform (Test 13) (High/Low Waveform is approximately 4 dB Higher in Power when both were Reported at 20W)

References

Capt. Diefel (GPSD) and Tom Powell (Aerospace) Emails on 25 April 2011 providing LSQ Test Sequence, LSQ power levels, and Balloon Pad Calibration data.

DOI

The Bureau of Land Management (BLM) arranged to have a number mapping and survey level receivers collect data during the LightSquared open sky testing at Holloman AFB. These receivers are a representative cross section of mapping and survey receivers that are currently in use within the BLM, other DOI agencies, and the U.S. Forest Service.

All of the mapping receivers that tested encountered problems with the exception of Receiver #26. Initial checking of the files showed that the collected data on the mapping receivers was only 70 to 75% of the possible yield. Receivers #27 and #28 had the worst point yields on both days of testing. When the data was further checked and compared to the test broadcast times two behaviors were noted. In the first case five or more satellites were tracked but the signal to noise (SNR) strengths of the satellites were below the usable software thresholds and positions were not computed. The second behavior was that the receivers lost lock on all satellites for a portion or the whole test. When the test signal was turned off the receivers would resume normal operation. The major issues with Receiver #29 occurred during the Test #1 full power testing on the Holloman Day 2 schedule and on the Test #5 test with a combination of signal strength decreases or no tracking. Interestingly the only receiver that did not have any tracking problems was Receiver #26. It should be noted that data was only collected during Day 2 of the Holloman AFB testing. Data was not collected on the third day due to the receiver being out of memory.

Receiver #30 and Receiver #31 both exhibited major problems in tracking with all tests. The typical behavior is that when a test signal was broadcast the receivers would lose total lock on the satellites and not track until the signal was turned off. This matches the behaviors seen by other government and industry testers of GPS and GNSS receivers.

Conclusions

GPS and GNSS technology is a major field data collection tool used by all resource management agencies. If the LightSquared implementation plan goes forward as proposed it will have a severe negative impact on the agencies' ability to efficiently and effectively collect data to manage our nation's resources. We will be severely limited in our use of GPS / GNSS real time survey receivers. We could potentially be forced to go back to total station surveys which will add costs in terms of operation and personnel. In addition the LightSquared plan could result in the Continually Operating Reference Station (CORS) GPS/GNSS network not being able to collect data and providing access to the National Spatial Reference System (NSRS). This will hamper our ability to collect or reference accurate geospatial data.

NOAA

NOAA / National Geodetic Survey participated in the NPEF sponsored LightSquared Live Sky testing at Holloman AFB on April 15, 2011. The NOAA vehicle was configured with four high precision geodetic / survey GPS receivers connected through an eight way splitter to a geodetic antenna using magnetic mounts on the vehicle roof. Another antenna similarly mounted was connected to a single survey receiver with the manufacturer recommended geodetic antenna. To maintain receiver anonymity in presenting the results random codes were assigned to the geodetic/ survey receivers tested. These codes were obtained from the LightSquared / United States GPS Industry Council (USGIC) Working Group Facilitator and will also be used in reporting NOAA results from the LightSquared Live Sky testing in Las Vegas May 18 - 22.

Due to high wind conditions on April 15th, the LightSquared Ancillary Terrestrial Component (ATC) reference station could only be raised to 32 ft. (9.8 m.) instead of the 100 ft. (30.48 m.) specified operational height. The NOAA vehicle was approximately positioned 315 m. (32 51 57.0N, 106 7 35.1W - ATC coordinate location) from the LightSquared transmitter for Tests #2, Test #3, and Test #4. After Test #4 the test director requested that the NOAA vehicle move about 100 m. closer to the LightSquared transmitter for the remainder of the testing that day. The NOAA vehicle was repositioned approximately 230 m. from the transmitter for Test #5, Test #9 (Ramp) and Test #7. The test conditions for all tests are noted in Table 5-17. The NOAA vehicle position on April 15th is shown in Figure 5-39.

Table 5-17. Live Sky Test Results, 15 April 2011

Test #2 – 5 MHz – High Band- Full Power	Event time (GPS)	Transmitted Power EIRP –Total (dBm)
Start Test	2:39:00	54.1
Added + 3dB to each port	2:42:00	57.1
End Test	3:09:00	57.1
Test #3 – 5 MHz – Low Band – Full Power		
Start Test	3:25:00	57.2
End Test	3:40:00	57.2
Test #4 – 10 MHz – Low Band – Full Power		
Start Test	3:54:00	57.2
End Test	4:09:00	57.2

Test #5 – 10 MHz – High Band – Full Power		
Start Test	4:22:00	57.2
End Test	4:37:00	57.2
Test #9 – Ramp - 5 MHz – High Band – Variable Power		
Start Test	5:08:00	Variable
End Test	5:50:00	Variable
Test # 7 - 10 MHz – High Band and 10 MHz Low Band – Full Power		
Start Test	6:05:00	54.2 dBm – One Channel
Added Second Channel	6:05:37	54.2 dBm – Each Channel
End Test	6:20:00	54.2 dBm – Each Channel

Figure 5-39. Live Sky Test Locations, 15 April 2011

The Test #2 results for receiver H07007A connected to geodetic antenna B through the splitter are shown in Figure 5-40. Receiver H07007A lost tracking at the start of the 5 MHz high band test and did not recover until the test was completed. The LightSquared transmitter was adjusted to output more power at GPS time 2:42:00 to 57.1 dBm, but receiver H07007A had already lost track at 54.1 dBm at the start of Test #2. The LightSquared transmitter at Holloman was not able to generate the maximum specified power of 62 dBm but could only achieve 57.1 dBm (approximately 5 dBm less than allowed). The test results in Figure 5-31 show the L1 C/A Signal to Noise Ratio as a function of time for each PRN tracked during Test #2.

Near the completion of Test #3 receiver H07007A was disconnected from the 8 position splitter and connected to a separate geodetic antenna (Antenna C) to provide a broader range of test data. Test #3 and Test #4 results for Receiver H07007A/C-antenna are shown in Figure 5-41. During Test #3 (5 MHz- Lower Band – Full Power) the Signal to Noise Ratio for all PRNs tracked by receiver-A dropped by about 5 dB. At the beginning of Test #4 the Signal to Noise Ratio dropped about 11 dB for all tracked PRNs. During the remainder of Test #4, the Signal to Noise Ratio dropped an additional 4 dB ending Test #4 with a net decrease of 15 dB for PRNs 7, 8, 17, 26 and 28. PRN 11 had a net decrease of 17 dB.

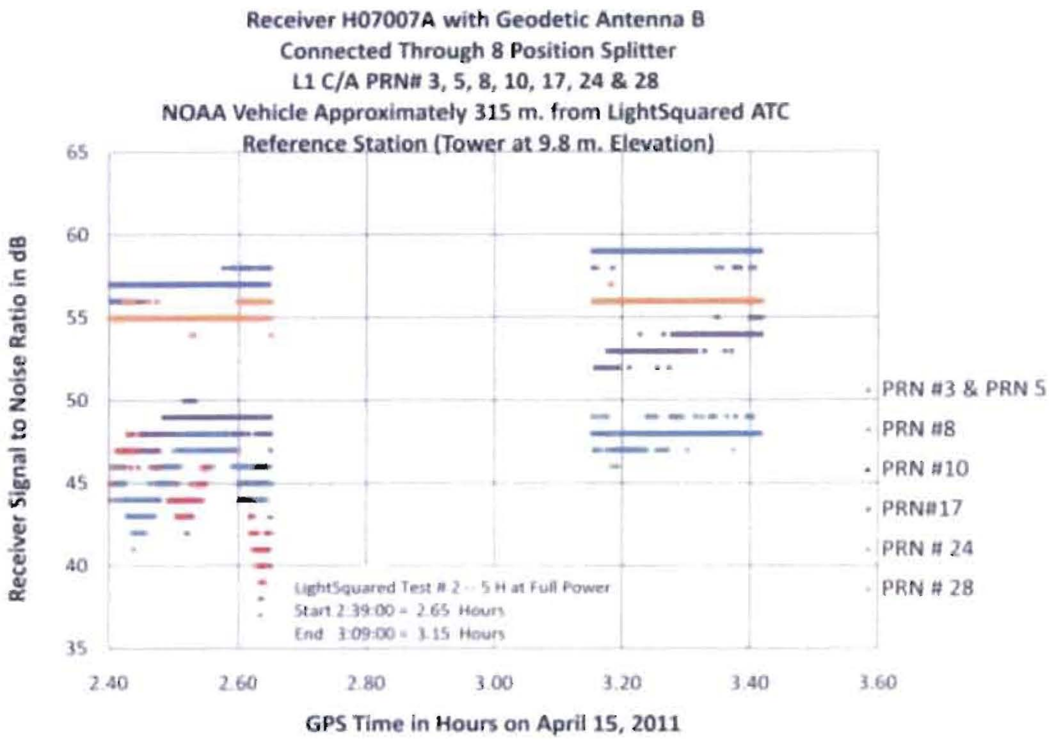

Figure 5-40. Results for Receiver H07007A with Antenna B

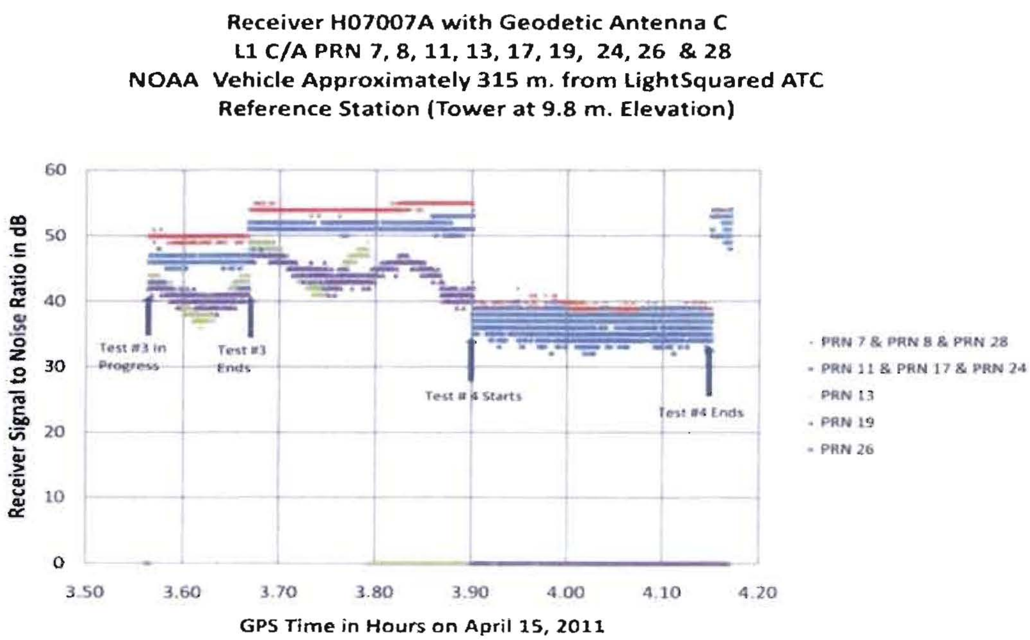

Figure 5-41. Results for Receiver H07007A with Antenna C

In addition to the 8 splitter receiver configuration at NOAA Test Site #1 another geodetic receiver (Receiver B/A-ant.) was also tested. The antenna connected to this receiver was a manufacturer recommended antenna. This receiver data acquisition was started after the 8 splitter receivers were set to take data and as a result Test # 2 was already over before the data acquisition was started for this receiver. However, no SNR degradation or loss of tracking was observed for Receiver B/A-ant during Tests # 3 and #4. The SNR degradation or loss of track for all receivers tested is summarized in Table 5-18 for NOAA Test Site #1 (315 m.). For receivers H92053, H80708 and H33451, the RINEX file conversion software were earlier versions of v2.11 and did not output the receiver Signal to Noise Ratios except in a compressed form which is not useful. The receiver performance for these receivers for the tests in Table 5-17 are summarized by noting positioning performance in Table 5-18 and Table 5-19.

Table 5-18. Summary of Receiver SNR Degradation or Loss of Tracking @ 315m from LightSquared ATC Transmitter

	Test #2	Test #3	Test #4
Receiver H07007A/B-ant.	All PRNs lose track and do not recover until Test # 2 is completed		
Receiver H07007A/C-ant.		Partial Data Acquisition – SNR ratios of all PRNs decreased by about 5 dB	SNRs for all PRNs tracked decreased 11 dB at beginning of test and dropped another 4 dB at the end of test
Receiver H07007B/A-ant.	No Data – Data acquisition started too late	No SNR degradation or tracking loss	No SNR degradation or tracking loss
Receiver H91389/B-ant.	5 PRNs lose track 4 seconds into test – all remaining PRNs lose track @2:54:48	3 PRNs lose track 3 seconds into test- the SNRs of the 6 remaining PRNs decrease between 17 to 19 dB – all remaining PRNs lose tracking @3:35:30 with 4:30 min. remaining in test	5 PRNs lose track 5 seconds into test- the SNRs of the 4 remaining PRNs decrease 14 to 25 dB - all remaining PRNs lose tracking @3:54:22- 22 seconds into test

Receiver H92053/B-ant.	15 minutes into test @2:54:13 less than 4 PRNs tracked – no position solution for remainder of test	3 seconds into test @3:25:03 less than 4 PRNs tracked – no position solution for remainder of test	6 seconds into test @3:54:06 less than 4 PRNs tracked – no position solution for remainder of test
Receiver H80708/B-ant.	13 seconds into test @2:42:13 less than 4 PRNs tracked – no position solution for remainder of test	4 seconds into test @3:25:04 less than 4 PRNs tracked – no position solution for remainder of test	4 seconds into test @3:54:04 less than 4 PRNs tracked – no position solution for remainder of test

The NOAA vehicle was moved after Test #4 from 315m to approximately 230m from the LightSquared ATC transmitter at the request of the Test Director. The SNR degradation or loss of track for all receivers tested in summarized in Table 5-19 for Test Site # 2.

Table 5-19. Summary of Receiver SNR Degradation or Loss of Tracking @ 230m from LightSquared ATC Transmitter

	Test #5	Test #9 (Ramp)	Test #7
Receiver H07007A/C-ant.	All PRNs lose track and do not recover until Test # 5 is completed	Tracking until 5:12:03 @42.4 dBm - then less than 4 PRNs tracked – no position solution for remainder of test	One second into test all PRNs lose track for the duration
Receiver H07007B/A-ant.	All PRN SNRs drop 1-5 dB at start of test; all PRN SNRs drop an additional 3 dB (3-8 dB) by end of test	Tracking until 5:26:37 @57.5 dBm - Max Power then less than 4 PRNs tracked – no position solution until 5:35:13 @51.5 dBm when tracking resumes with 4 PRNs	No SNR degradation for 2 PRNs and 1-4 dB degradation for remaining PRNs at start-30 seconds into the test 7 PRNs lose tracking and remaining 3 PRNs SNRs decrease an additional 14 dB

Receiver H91389/B-ant.	5 PRNs lose track 4 seconds into test – all remaining PRNs lose track @2:54:48	Tracking until 5:16:54 @47.5 dBm - less than 4 PRNs tracked – no data until 5:40:37 @45.4 dBm when tracking resumes with 4 PRNs	3 seconds into test @6:05:03 less than 4 PRNs tracked – no position solution for remainder of test
Receiver H92053/B-ant	29 seconds into test @4:22:29 less than 4 PRNs tracked – no position solution for remainder of test	Tracking until 5:25:46 @56.5 dBm - then less than 4 PRNs tracked – no position solution until 5:41:26 @45.4 dBm when tracking resumes	30 seconds into test @6:05:30 less than 4 PRNs tracked – no position solution for remainder of test
Receiver H80708/B-ant.	4 seconds into test @4:22:04 no PRNs tracked – no position solution for remainder of test	Tracking until 5:14:09 @44.4 dBm - then no PRNs tracked – no position solution for remainder of test	RINEX file ends @5:14:09 – No data for Test #7

The GPS accuracy of Receiver H07007 A/ C-antenna was determined using NOAA / NGS post processed software during the time interval between the end of Test #3 and the beginning of Test #4 (Figure 5-41). The application computes differential position coordinates using the closest CORS reference station to the NOAA vehicle. The Receiver H07007A/ C-antenna accuracy relative to the average vehicle coordinate when the LightSquared reference station was not transmitting is shown in Figure 5-42. The NGS post processed 95% accuracy is three meters or less with CORS reference stations up to 200 km. from a rover position. The receiver H07007A/ C-antenna accuracy during LightSquared transmitter Test#4 is shown in Figure 5-43. The 95% position accuracy of Receiver A/ C-antenna degraded from 2.6m to 3.1m and more outliers occurred during Test #4. The GPS accuracy of Receiver B/A-antenna was measured during Test # 5 and no degradation was noted as the PRN SNRs decreased 3-8 dB (Table 5-19).

The carrier phase accuracy was determined using NOAA / NGS product OPUS-RS. OPUS (Online Positioning User Service) is a free Web-based utility enabling its users to submit GPS data to NOAA's National Geodetic Survey where it will be automatically processed to obtain precise coordinates for the location associated with this data. The biggest difference between OPUS and OPUS-RS is the occupation time. OPUS requires a minimum occupation time of at least two hours and OPUS-RS requires a minimum occupation time of fifteen minutes. The LightSquared ATC transmissions in different phases during the testing on April 15 were 15 minutes in duration for all tests except for the ramp test (Test # 9) which lasted about an hour.

OPUS-RS also has the capability to estimate the accuracy and availability at a given coordinate for 15 minute and one hour data sets. Table 5-20 lists the predicted and measured carrier phase accuracy for Receiver H07007A/C-antenna. This is the only receiver to maintain tracking and experience SNR degradation during a LightSquared ATC test without losing tracking. Carrier phase accuracy was not measured for Receiver H07007A/B-antenna as this receiver did not experience any SNR degradation or lost tracking during Test #4.

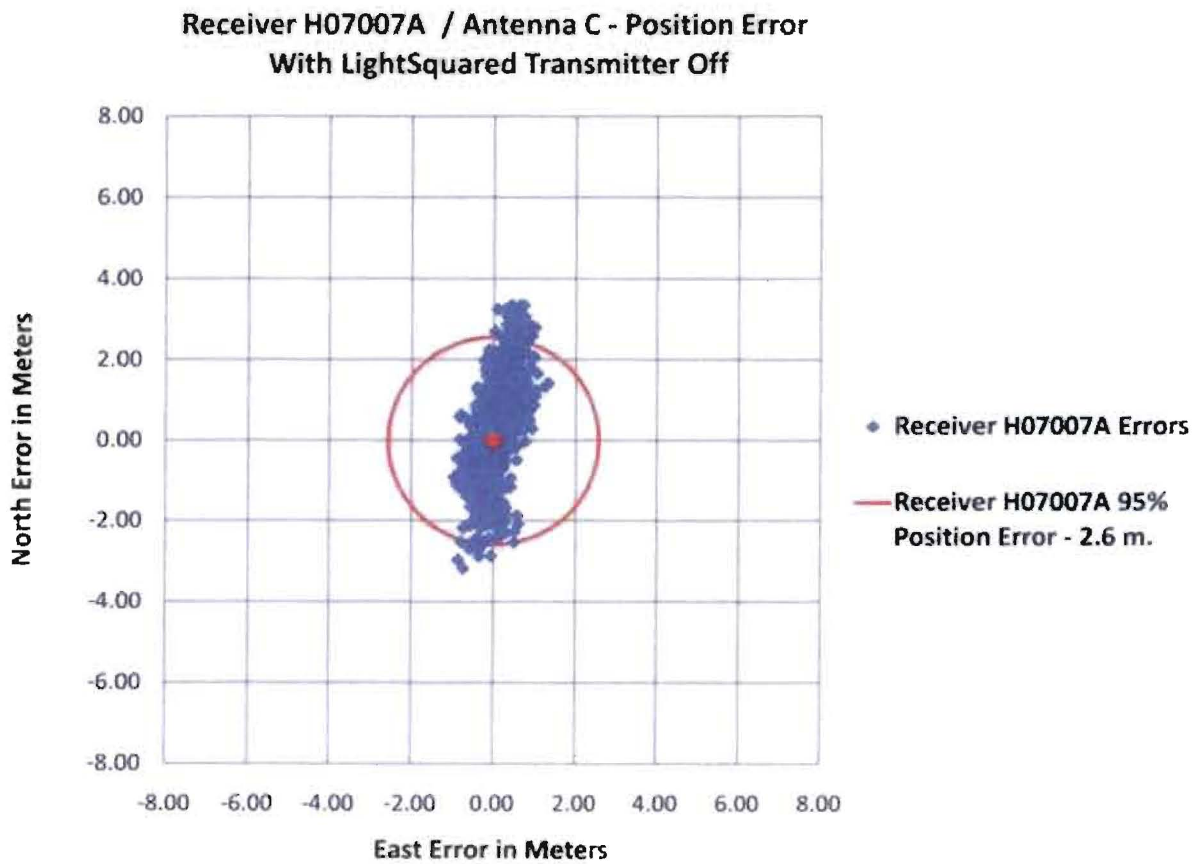

Figure 5-42. Receiver H07007A/Antenna C Position Error with LightSquared Transmitter OFF

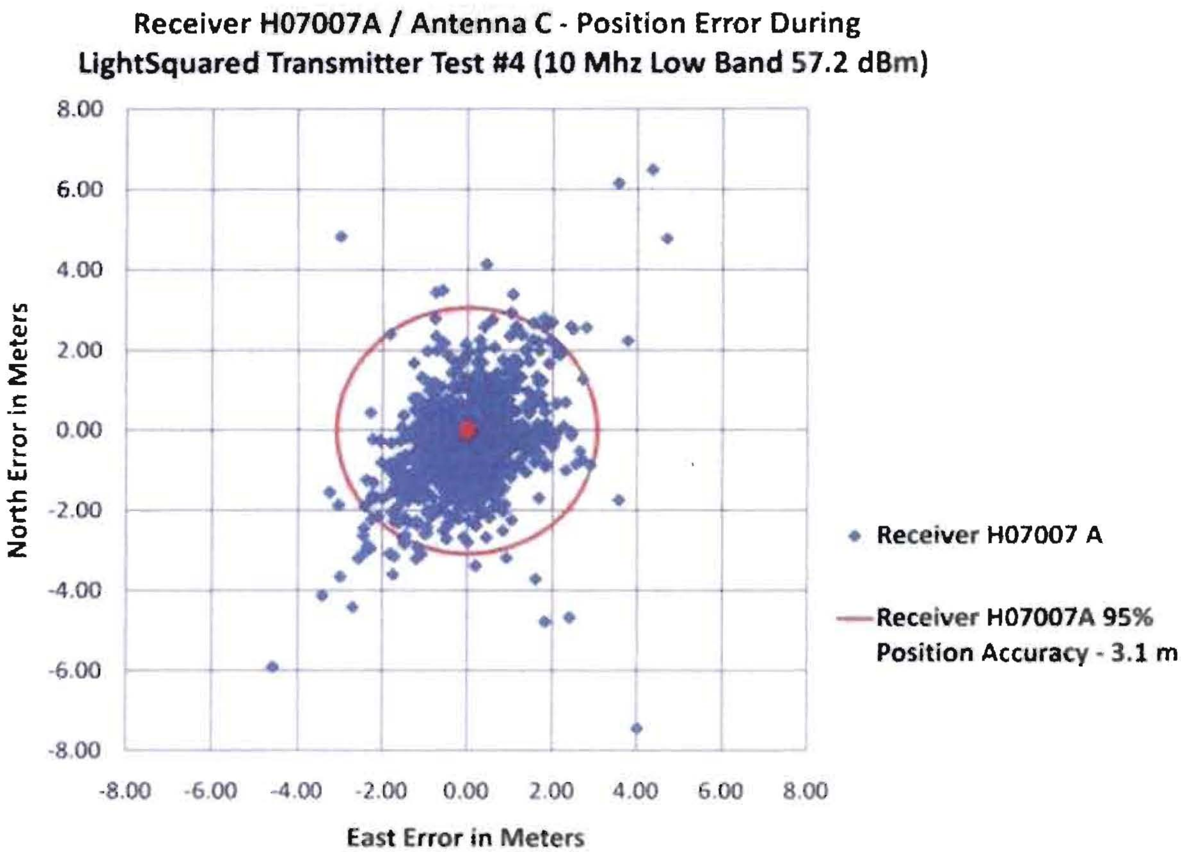

Figure 5-43. Reciever H07007A Position Error with LightSquared Transmitter ON (10MHz Low Band 57.2 dBm)

Table 5-20. OPUS-RS Carrier Phase Accuracy During Test #4

	95% Predicted Position Accuracy	95% Measured Position Accuracy
Receiver H07007A/C-ant. Test site #1	2 cm.	1.2 cm Test # 4 (898 Data Points)

Summary Analysis and Conclusions

Most geodetic survey receivers lost tracking at 315 meters or less from the LightSquared ATC reference transmitter station. The better performance was provided by Receiver H07007B/A-ant. (connected to the manufacturer recommended antenna). No SNR degradation or tracking loss was observed for this receiver during Test #3 (5 MHz – Low band – Full Power) or Test #4 (10 MHz – Low Band – Full Power). During Test #5 (10 MHz – High Band – Full Power) this receiver experienced 3-8 dB SNR degradation but no degradation in pseudorange or carrier phase accuracy. Receiver H07007B/C-antenna (connected to a separate geodetic antenna instead of the common antenna in the splitter) experienced about 15 dB SNR degradation and also had a 0.5m.decrease in pseudorange accuracy during Test #4. There was no degradation in carrier phase accuracy (Table 5-20) for this receiver. The remaining three GPS receivers (H91389, H92053 and H80708) connected to common antenna B through the splitter all lost tracking during Test #2, Test #3, and Test #4. All receivers lost track during Test #5 and Test #7 except as noted above for Receiver H07007B/A-antenna. All receivers lost tracking during the Ramp test and either resumed tracking as the power was decreased or were not able to reacquire the GPS satellites for the remainder of the ramp test. Test# 5, Test #9, and Test #7 may also be more severe as the 5 and 10MHz high bands were transmitted at full power which are closer to the GPS band.

This data set may not qualify as official data for the Holloman AFB Live Sky testing as the LightSquared ATC tower height was only at 32 feet instead of the operational height of 100 feet for the subsequent days of testing. However, this data set may be a preview of what can be expected during the LightSquared Live Sky testing in Las Vegas. Three of the four LightSquared ATC reference stations will have antenna heights between 15.2 – 18.3 meters compared to the NOAA data set logged at the 9.8 meter antenna height.

National Continuously Operating Reference Station (CORS) System

The National Geodetic Survey has established a national CORS system to support non-navigation post-processing applications of GPS. More recently, the CORS network has also served a troposphere and ionosphere monitoring network by those two scientific communities. Additionally, the national CORS is being modernized to serve as the foundation for future applications that support near- and real-time positioning (differing from navigation applications by the lack of a safety-of-life component). The national CORS system provides code range and carrier phase data from a nationwide network of GPS stations for access by the Internet. As of March 2005, data were being provided from more than 650 stations.

The NGS manages and coordinates data contributions from GPS stations established by other groups rather than by building an independent network of reference stations. In particular, use is being made of data from stations operated by components of DOT and DHS that support real-time navigation requirements (mostly WAAS and NDGPS). These real-time stations make up approximately 26 percent of all national CORS stations. Other stations currently contributing data to the national CORS system include stations operated by the NOAA and NASA in support of crustal motion activities, stations operated by state and local governments in support of surveying applications, and stations operated by NOAA's Forecast Systems Laboratory in support of meteorological applications.

The national CORS is a GPS augmentation system managed by NOAA that archives and distributes GPS data for precision positioning and atmospheric modeling applications. It serves as the basis for the National Spatial Reference System, defining high accuracy coordinates for all CONUS-based Federal radionavigation systems. Historically, CORS served post-processing users of GPS, but is being modernized to support real-time users at a similar level of accuracy.

State of New Mexico Emergency Services

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May 11, 2011

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Dear Colonel Gruber, Ms. Van Dyke and Mr. Nagle:

In March 2011 I was informed of a company called LightSquared that is asking for FCC approval to build a nationwide 4G wireless network. There is concern from major GPS providers that LightSquared's frequency interferes with GPS signals necessary for routine 911 caller location.

I was asked by the Federal Aviation Agency (FAA) to coordinate first responder representatives from fire, EMS and law enforcement for testing of the LightSquared network in a live sky testing environment at Holloman AFB, New Mexico on April 15 – 16, 2011. The objective of the test was to determine if any level of interference to GPS signals were a result of LightSquared testing.

The attached reports are provided by law enforcement, EMS and fire first responders who participated in the field test. Law enforcement was represented by New Mexico State Police personnel Mike De Fausell and Officer Daniel Vaughan of New Mexico State Police District 4 office in Las Cruces. Mike is a subject matter expert in communications technology with an emphasis on radio. The attached reports verify there was a negative effect on the GPS equipment.

EMS and Fire reports are from local government first responders from Otero County. They represent typical fire and EMS field equipment. See the attached report from Otero County Emergency Manager Paul Quairoli detailing anomalies in GPS reception.

In conclusion the attached reports substantiate concerns that the LightSquared network will cause interference to GPS signals and jeopardize 911 and public safety nationwide.

If you have any questions, please feel free to contact me at 505-827-4804 or bill.range@state.nm.us.

Sincerely,

Bill Range

Bill Range, ENP, PMP
New Mexico E-911 Program Director
Department of Finance and Administration, Local Government Division

<u>LightSquared Test</u>

On April 15, 2011, at approximately 2354, we experienced system failure when we parked under the LightSquared tower. Once the power was shut off at the tower, we left the tower site. When we got to the turn off for the dirt road, the system came back up and the Alamogordo office was able to see us moving again.

Our system has cell phone connectivity, radio connectivity, and satellite connectivity. Our mobile data terminal will automatically select and connect to the strongest signal. The GPS is only over the satellite transceiver.

When the tests were started again our GPS positions were skewed. When the LightSquared tower was turned off the system would normal out.

I believe it was approximately 0400 when they began the high dual five test, the GPS positions were skewed and remained skewed even after power was turned off. As they began the next tests, we started getting GPS reading from the Alamogordo office every ten minutes. These GPS readings continued to be incorrect the rest of the test period. We asked the Alamogordo office to send the GPS readings with the time via the MDC so there would be a record of the information.

We were unable to get the system to normal out until we were leaving Holloman AFB on April 16, 2011 at approximately 0700; we did another reset of the equipment. At that point the system began to function correctly.

My times and GPS reading were given to Captain Justin Deifel, USAF at the closing briefing.

Submitted by:

Mike De Fausell
New Mexico State Police
District Four Communications

6. Subtask 6 - Simulation Activities

Task Statement

Coordinate simulation activities to further assess effects on GPS usage under various scenarios.

NASA Simulations

Overview

This report describes analysis of LightSquared base station interference to four high-precision GPS receivers used in NASA spaceborne and terrestrial applications. All four receivers are capable of processing the L1 C/A-code and L1/L2 P(Y) code GPS signals. The P(Y) code signals are processed using various semi-codeless techniques to obtain the L2 carrier phase. Interference assessment is based on estimating the interference levels expected in various spaceborne and terrestrial scenarios and comparing them against interference limits/thresholds obtained through conduction measurements on the four receivers by JPL. This testing was performed at JPL on March 22, 2011 using a simulated LightSquared Phase 1 signal (i.e., two 5 MHz channels centered at 1528.8 MHz and 1552.7 MHz) and is described in the previously distributed report, "A Preliminary Report on the Effects of Conducted LightSquared Emissions on Four High-Precision GPS Receivers." LightSquared provided filters for this conducted testing and a LightSquared representative participated in the testing. The spaceborne analysis includes both an atmospheric radio occultation (RO) application where the GPS receiver antenna is directed towards the Earth limb in order to measure properties of the atmosphere and the more typical navigation application where the GPS receiver antenna is pointed upwards to obtain spacecraft position, velocity, time and/or attitude. Two precision terrestrial receivers used in the IGS (International GNSS Service) and SCIGN (Southern California Integrated GPS Network) are also examined.

Analysis Assumptions

Table 6-1 shows the GPS characteristics and LightSquared base station characteristics used in the various analyses. Three types of analysis were performed: (1) aggregate base station interference into spaceborne GPS receiver; (2) interference from single base station into terrestrial receiver; and (3) aggregate base station interference into terrestrial receiver. For the space receiver analysis, 3 cases were considered: (a) radio occultation (RO) receiver onboard COSMIC-2 satellite in 800 km/72° inclined orbit (see Figure 6-1); (b) RO receiver onboard COSMIC-2 satellite in 520 km/24° inclined orbit; and (c) navigation receiver onboard typical LEO in 400 km altitude orbit.

GPS Receiver Characteristics

Spaceborne Receiver Analysis

For the spaceborne receiver analysis a MATLAB simulation program was developed to model the receiver onboard a satellite in various orbits and interference statistics calculated for a LightSquared base station deployment of base stations distributed among certain cities in the US. This city data was provided by LightSquared but has been redacted in this report for proprietary reasons. Two types of space receiver applications were considered: (1) the RO application which involves pointing the GPS receiver antenna towards the earth limb in order to receive GPS signals traversing the atmosphere; and (2) the more typical navigation application in which the antenna is pointed in the zenith direction towards the GPS constellation. In both cases interference thresholds for the TRIG and IGOR space receivers (as determined by the JPL conduction testing) are considered.

The TRIG and IGOR receivers are designed for RO measurements but can also be used for navigation/Precision Orbit Determination (POD). In the RO technique a GPS receiver in LEO observes the propagation delay of GPS signals which travel through the atmosphere. Occultations occur as each GPS satellite rises or sets on the horizon as viewed by the space receiver. From the changing delay, the (altitude) variation in the atmosphere's index of refraction can be measured and altitude profiles of ionosphere electron density, atmospheric density, pressure, temperature, and water vapor can be derived. Consequently, the receiver antenna main-beam is directed towards the earth limb (and also, in this case, the main-beams of the interfering base stations). JPL is planning the next generation of RO measurements with receivers onboard the COSMIC-2 constellation, which will have initial launch in 2014 and consist of six satellites in a 520 km orbit at 24 degrees inclination and six more at 800 km orbit and 72 degrees inclination. Each satellite will have actively steered array antennas with approximately +15 dBic gain directed along the limb of the earth in the forward (for rising GPS satellites) and aft (for setting GPS satellites) directions. Figure 6-2 shows the gain pattern for the forward antenna with the main-beam directed 26.2° below the satellite velocity vector towards earth limb. The 12 elements of the array are on a 60 cm tall x 40 cm wide mounting plate and mounted on the front of the spacecraft so that the plate is vertical and the outward normal to the plate is parallel to the spacecraft's velocity vector (assuming circular orbit).

The TRIG is the next generation NASA/JPL RO receiver designed to work with new signals from GPS and other GNSS satellites. It can also be used for POD. It has a very wide RF pre-select filter (i.e. 3 dB bandwidth from 1100 MHz to 1660 MHz) to allow the receiver to be reprogrammed in flight to different frequencies over the full range of GNSS signals. The wide bandwidth also results in lower insertion loss, less variation of signal delay and phase with temperature, and allows newer processing techniques by using a signal bandwidth much greater than the conventional 20 MHz.

The IGOR is the current generation RO receiver based on the NASA/JPL Black Jack space receiver. These receivers have been deployed as primary science payloads on the COSMIC mission, TerraSAR-X, Tandem-X, and TACSAT-2 missions. IGOR has a wideband pre-select filter and narrowband L1 and L2 filters. IGOR can also function as a POD GPS receiver.

For the usual space navigation application, the TRIG/IGOR receivers are assumed to use a zenith pointed choke ring antenna with 6.8 dBic gain with gain pattern shown in Figure 6-3. For this